NORMAL BLOOD SUPPLY TO EQUINE RADII AND
ITS RESPONSE TO VARIOUS CERCLAGE DEVICES

by

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INTRODUCTION

It is well known that fractures of equine long bones are difficult to successfully repair. Though equine surgeons frequently express a desire for a cerclage-type device to aid in reduction and stabilization of long bone fractures, these appliances are not currently popular. A major reason cited for the lack of acceptance of cerclage techniques in equine surgery is that the large (wide) cerclage devices required to maintain stable anatomic reduction of the fracture will severely compromise the cortical blood supply.

The functional blood supply to human and canine bone has been studied in exquisite detail by Rhinelander, Brooks, and others utilizing microangiographic techniques.[1,2,3,4,5,6,7,8] Microangiography has been employed to examine changes in the osseous vasculature under varying conditions of post fracture osteogenesis including displaced and nondisplaced fractures, standard plate fixation, cerclage fixation using wires and Parham - Martin bands, and intramedullary nailing.[2,4,7,9-11]

There are no known studies to date on the normal or altered arterial supply to the long bones of the horse. This study examined the normal arterial blood supply to the equine radius and the reaction of the blood supply beneath three cerclage devices.

LITERATURE REVIEW

Blood Supply of the Mammalian Long Bone

The skeletal system persists long after the associated soft tissue components of the animal's body have decomposed. The solidarity of bone as its primary characteristic leads one to erroneously consider bone inert. In reality, bone is extremely dynamic and is continuously remodeled throughout the individual's life. All of the physiologic processes of the skeleton are dependent on the blood supply to the bone.

In 1674, Antonie van Leeuwenhoek described small vessels entering into the cortex of a calf tibia. Clopton Havers published a book in 1691 which described a nutrient artery piercing the bone cortex to ramify in the medullary cavity. He described a series of "straight channels" in the bone cortex of man and ox. These channels, soon to be known as Haversian canals, formed part of the circulatory route of minerals and nourishment for the compactum. Havers also described the vast complex of veins in the periosteum, establishing the first written theory of the centrifugal flow of blood through the cortex.[2] Albinus (1756) described tiny blood vessels contained within the Haversian canals. Because Albinus was a greatly respected authority on blood circulation, the earlier descriptions made by Leeuwenhoek and Havers became widely accepted.[2] Present day theories of the blood supply to the long bone stem from the basic observation of these early scientists more than two centuries ago.

The basic anatomy of a long bone is similar in all species. The bone consists of a shaft (diaphysis) which widens at each end to form

the metaphysis. In young growing bone, the metaphysis is capped by the epiphysis. Articular cartilage covers each end of the long bone to provide a smooth surface for proper joint articulation. The diaphysis is a hollow cylindrical tube with thick walls consisting of dense cortical bone (compactum) that becomes thinner at the metaphyseal junction. The medullary cavity contains hemopoeitic tissue and the vasculature necessary to nourish the bone marrow and compactum. The metaphysis is primarily cancellous bone covered by the thinner cortical walls.[2,3]

Periosteum provides a membranous covering over the entire cortical surface except for the articular surfaces. The periosteum consists of two layers. The inner osteogenic layer is present on young or injured bone. The cells in this layer contribute to circumferential enlargement or bone remodeling. In mature bone, this layer is primarily comprised of extensive capillary networks. The fibrous outer layer predominates in mature bone where this layer is loosely attached to the diaphyseal cortex. In areas of ligamentous or fascial attachments (linea aspera of the femur), the fibrous periosteum is very strongly attached to the periosteum.[3]

The typical long bone of mammals receives its arterial blood supply from three major sources: 1) the nutrient artery; 2) the metaphyseal arteries (which anastomose with epiphyseal supplies after growth plate closure); and 3) periosteal arteries.[1-8] Vaughn and Rhinelander describe these vessels as the afferent vascular system.[1,8]

One nutrient artery is usually present for a given long bone. The nutrient artery arises directly from an artery of the systemic circulation. It enters and passes through the compactum obliquely and

divides into the ascending and descending medullary arteries within the marrow cavity. The medullary arteries then divide into arterioles that penetrate the endosteal surface to supply the diaphyseal cortex as the end arteries.[1]

The metaphyseal and epiphyseal blood supply varies with maturity of the long bone. Many nutrient foramina can be found at the ends of long bones.[2] In the young bone, a separate epiphyseal and metaphyseal blood supply exist separated by the cartilagenous growth plate.[1] With age and subsequent growth plate closure, the metaphyseal arteries anastomose with the medullary arteries.[1]

The periosteal arterioles enter the diaphyseal cortex only at areas of heavy fascial attachments. At this location, the arterioles may anastomose in the outer one-third of the cortex with vessels derived from the medullary circulation. These periosteal arterioles may aid in the nutritional supply to the compactum in this area, but not in areas of loose periosteal attachment.[1]

The efferent vascular system as described by Vaughn consists of the 1) large emissary veins and nutrient vena comitans of the nutrient foramen; 2) cortical venous channels; and 3) periosteal capillaries.[1]

The emissary vein and nutrient vena comitans arise from the central venous sinuses of the medulla and largely drain the marrow and, to a lesser degree, the endosteal cortical surface.[1]

The cortical venous channels are numerous and are described as draining most of the compactum. These venous channels are easily visualized when periosteum is stripped from the diaphysis of a healthy bone. They can be seen as spots of blood exiting the compactum surface. If left undisturbed, the venous channels empty into the surrounding soft tissue.

The periosteal capillaries are a vast network of vessels in the inner layer of periosteum. These capillaries are continuations of the venous channels of the diaphyseal compactum and thus are the final participants of the centrifugal flow of cortical blood.[1,8]

Rhinelander states that the anatomic location of the afferent arteries may differ between mammalian species, but the fundamental supplies are the same.[6] The fundamental blood supply to the long bone has been studied in exquisite detail by Rhinelander, Brookes, and others.[1-7,9-11] Most workers agree that the primary arterial supply to the cortex includes both the nutrient and metaphyseal-epiphyseal arteries.

Historically, the contribution of the periosteal vessels to the afferent cortical blood supply is controversial. Brookes and Harrison (1957) performed microangiographic analysis of the cortical blood supply to the rabbit tibia.[12] In this study, they described fine arterial pathways entering the endosteum from medullary arterioles, yet no centripetal vessels were noted entering the cortex from its periosteal surface. This concept has been supported by McNab (1957), McAuley (1958), Jackson and McNab (1959), Nelson et al. (1961), Rhinelander and Baragry (1962), and Rhinelander (1968).[9,10,12-16]

Other workers oppose this view. Trueta (1963) considers that the outer one-third of the cortex is supplied by the periosteal vessels.[11,17] Opponents to this theory argue that Trueta utilized young experimental animals with a very active osteogenic periosteal layer.[2,6,11] Crock (1967) published microangiograms demonstrating periosteal vessels entering the diaphyseal cortex.[18] Brookes contends that Crock utilized senile or pathologic specimens in this studies which

may have increased periosteal arteries as a result of old age, osteoporosis, or pathology.[2]

It has been suggested that periosteal blood supply contributes to the cortical blood supply of mature long bone only when damage has occurred to the endosteal supply.[4,19] Rhinelander contends that this may be true under varying circumstances. He states the periosteal arterioles supply the outer one-third of the cortex in areas of dense fascial attachments or in areas where the endosteal supply has been occluded. In the normal healthy bone, Rhinelander states the blood flow is centrifugal (endosteal to periosteal). Periosteal afferent contribution to the cortex is minimal.[2,6,7,9]

The centrifugal supply of blood to the cortex has been supported in numerous studies. Brookes (1964) suggests that studies of many other investigators support centrifugal flow. Evidence cited includes the perfusion of sulfate solutions from the marrow to the cortex but not into the periosteum; the slow perfusion of intravital dyes from the marrow into periosteum; the diminished intensity of radioactive ions from medulla to periosteum in autoradiography studies; and the inability of India ink, which can readily traverse capillaries, to enter the cortex via periosteal vessels when the nutrient arterial system has been ligated.[4]

In summary, the centrifugal blood supply of normal mature mammalian long bone includes three afferent sources. The nutrient and metaphyseal-epiphyseal arteries contribute the vast majority of the afferent supply. Periosteal arterioles may contribute a minor supply to the outer cortex in areas of dense fascial attachments or bone repair. Branches of the medullary arterioles are continuations of the nutrient

artery; these vessels supply the medullary cavity and enter the endosteum to supply the cortex. The efferent vasculature consists of cortical venous channels that emerge on the outer surface of the compactum and drain through interfascicular venules, the emissary veins which drain primarily the medullary cavity, and the periosteal capillaries, which drain the capillaries of the external layers of the diaphyseal cortex.

Microangiography and Related Infusion Techniques

Microangiography is the most widely accepted technique for viewing the blood supply of bone. Several perfusion methods have been utilized for the infusion of osseous vasculature including India ink, colored liquids and plastics.[4] None of these media have demonstrated the reliability and repeatability of microangiography.

The Spalteholz technique involves the perfusion of India ink through the osseous afferent vasculature. The tissues are then cleared by immersion in a series of solutions. This infusion technique is useful for highlighting small vessels under light microscopy. The Swedish workers Olerud and Danckwardt-Lilliestrom (1969) utilized the Spalteholz technique in combination with flurochemical labeling (tetracycline) to evaluate fracture repair in the canine.[2,20,21]

Colored liquid infusion refers to viscous synthetic liquids that harden after injection (latex). This infusion technique is most often employed by gross anatomists. The technique is not satisfactory for evaluation of the osseous blood supply. The latex media will not effectively perfuse the microvasculature even when injected at high pressures.[2,22]

Neoprene, a plastic material, has been injected into the vascular system. Wray and Lynch (1959) injected methylmethacrylate into the arterial tree of rats whose lower limbs had sustained previous fractures. After solidification, the osseous tissue was removed by immersion in strong acid solutions. The resulting vascular remains were compared quantitatively by weight to normal legs.[2,22,23] These plastic compounds are injected by high pressures, however, as with the latex products, only afferent vessels to the arteriolar level are perfused. The microvasculature is poorly defined by this technique. For this reason, the use of methylmethacrylate in osseous vascular studies is limited to large afferent vasculature.

Microangiography is a technique that has been used successfully to study the osseous vasculature by many researchers during the past 25 years.[2,6,7,9,10,12-16,24-28] Its advantages include: the utilization of a small particle size (.5 µm) which is capable of perfusing capillaries, sinusoids, and the vascular lattice of the compactum, the technique of preparation allows microangiograms and histologic sections from the same tissue, and the barium sulfate media is visible in both histologic as well as microangiographic sections.[29]

Rhinelander's technique involves the infusion of the major arterial supply of the limb under study with a 30 percent by weight suspension of barium sulfate in saline at 120 mmHg. Prior to infusing the artery, the animal is heparinized and euthanized. Infusion of media at normal pressures insures that only the functional blood supply to the bone is perfused and that production of artifactual channels is avoided.[22]

The bone is decalcified and cut into 1 mm thin sections for radiography. When the microangiograms have been completed, the same

sections are recut on a microtome and stained for histologic evaluation. This method insures that the same tissue studied via microangiography is also studied histologically which allows excellent correlation of data. The microangiograms are frequently made in stereoscopic pairs to further characterize the multitude of blood vessels present in each 1 mm section.[22]

Other investigators (Trueta 1947) alternate cutting thick (1 mm) and thin (10 μm) slices of bone for microangiography and histology, respectively. This insures that adjacent areas of bone are studied via both methods of evaluation.[24] This technique has been widely utilized and is less time consuming, however, it is generally accepted to be less accurate than Rhinelander's technique.[22]

Microangiography has also been utilized to examine changes in the osseous vasculature under varing conditions of postfracture osteogenesis including displaced and nondisplaced closed fractures, osteotomy and standard plate fixation, compression plate fixation, cerclage device fixation, intramedullary fixation with loosely fitting rods, medullary reaming and fixation with an intramedullary nail that fills the medullary cavity completely.[2,4,7,9-11,29] Microangiography has also been utilized to study the vascularization of cancellous bone grafts in incomplete and complete long bone defects.[1]

Cerclage Devices

Cerclage devices are generally metallic appliances, usually surgical stainless steel, that are utilized by circumferential application to long bones for stabilization of long bone fractures. These devices are most commonly applied to diaphyseal spiral or oblique

fractures. The use of steel wires, flat bands, radiator hose clamps, and nylon straps have been reported as circumferential stabilizing appliances in the literature.[30-43]

Cerclage wire is composed of surgical stainless steel. Eighteen to twenty-two guage round wire is most frequently utilized in small animal orthopedics. Because cerclage wires are round, they contact minimal surface area on the compactum and, therefore, minimally compromise centrifugal blood supply.[29] Using microangiographic methods, Rhinelander demonstrated that properly applied cerclage wires did not compromise osseous vasculature, as evidenced by the extensive callus formation and the lack of abnormal histopathological findings.[1,2,6,9,10,29] Histologic sections of cortical bone from beneath tightly applied cerclage wires demonstrated an absence of osseous necrosis. Microangiographic evaluation of the bony callus revealed the perpendicular orientation of the arterioles through the callus to the cortical surface. This confirmed that the wires did not interfere with the normal blood supply of the cortical bone.

The use of cerclage wires for fracture fixation in orthopedics has not been universally endorsed.[29,36,37,39,40,42] More recently, discussion of the success and failure of cerclage wires has centered around the use of proper application technique.[37,39,41] Newton and Hohn (1974) reported clinical cases of fracture nonunion resulting from the use of cerclage wires in fracture repair.[42] The authors cited eight cases of fracture fixation using cerclage wires and intramedullary Steinman pins that resulted in nonunion fractures. In their opinion, the diaphyseal afferent vascular supply was provided by two sources. The nutrient artery supplies the diaphyseal cortex as its primary source

in healthy bone. The longitudinal periosteal vessels aided in cortical vascularity to a significant degree only when the medullary (nutrient artery) supply had been interrupted. The opinion was held that dissruption of the medullary vasculature by the intramedullary pin and concurrent interference of the longitudinal periosteal vasculature by the cerclage wires resulted in a clinical nonunion of eight fracture cases. Nonunion results as the bone near the fracture becomes ischemic and acidotic resulting in a suboptimal environment for osteoblastic activity. Inadequate immobilization was also mentioned as a cause for fracture nonunion.[42]

Hinko and Rhinelander subsequently published a report of clinical observations indicating that proper utilization of cerclage wires and intramedullary pins would result in adequate fracture reduction, fixation, and uncomplicated healing.[38] Rhinelander cited his previous research of long bone blood supply to support this clinical study.[1,2,17] The authors stated that the periosteal vascular supply is minimally involved in fracture repair. As previously noted, the blood supply to the external callus is in a perpendicular orientation to the long axis of the diaphysis and, thus, would not be interrupted by application of a cerclage wire. During the initial stages of fracture healing, the medullary vascular supply to the cortex is rapidly reestablished to remain the primary source of nourishment for healing bone. The authors contend that the longitudinal periosteal capillary networks are present only in immature bone. In fracture healing, the periosteal capillaries readily grow around cerclage wires, causing no impairment of blood supply. For these reasons it was suggested that poor surgical technique was the major factor contributing to clinical nonunion of fractures

subsequent to fixation with wires and intramedullary pins. Principles for successful use of cerclage wires when used with intramedullary nails include: placement of the cerclage wires directly on the periosteum, minimal fascial disturbance when positioning the wires around the cortex, utilization of at least two wires to prevent a "fulcrum" effect, tightening cerclage wires to a similar tension, positioning of the wires at least 1 cm apart and .5 cm from the oblique fracture fragments, and never placing the wire in the fracture line. Ten clinical cases were cited with excellent success adhering to these principles. Improper technique in the application of cerclage wires is the most common cause for nonunion of fractures.[38]

Withrow and Holmberg (1977) supported Hinko and Rhinelander by reporting 18 cases of successful long bone fracture fixation using cerclage wires.[41] Withrow and Holmberg cited the perpendicular nature of periosteal vascular supply within the cortical bone as the primary argument for the success of cerclage wires. Improper technique of wire application and improper case selection were suggested as the major cause of failure using cerclage wires. Gambardella (1980) acknowledged the use of cerclage wires as an effective means of fracture fixation.[37] Twelve principles of proper technique were given to aid the surgeon to successful results utilizing cerclage wires.

Parham-Martin bands were introduced for fracture repair in 1913.[30] The band, comprised of surgical stainless steel, is broad (5-10 mm) and flat in shape. Parham bands have not met with the favor cerclage wires have ultimately received. Rhinelander suggested that the width of the Parham band interfered with the centrifugal blood flow by occluding the efferent periosteal vasculature resulting in passive congestion of the

cortical bone leading to local ischemia and acidosis.[6,7,29] Annis (1982) cites the successful use of Parham-Martin bands in six canine long bone fracture cases.[31] Annis recommends that the bands should be removed following clinical healing of a fracture to reduce the subsequent development of avascular necrosis, rarefying osteitis, or secondary fracture.[31] Periosteal callus does not grow over the Parham-Martin band and thereby delays healing.[29]

A nylon cerclage device was introduced by Partridge in 1976.[33-35] This cerclage was designed to be self-locking and has a series of projections on its inner surface which serve to position the strap off the cortical bone to prevent compromise of the cortical circulation. Nylon 66 is both strong and nonreactive in body tissues.[33] Experimental studies in humans by Brookes and Heatley have shown no significant interruption to the circulation with this device.[34,35] Partridge stated that the projections on the inner surface of the strap prevent disruption of centrifugal cortical blood flow.[34] A clinical case review of geriatric femoral fractures has shown the Partridge strap to be an effective aid in the fixation of human long bone fractures. The use of nylon cerclage with intramedullary nailing provided stable fixation and eliminated the need for traction -- a treatment that carries risk of multiple medical complications in the geriatric patient. Patients with a hip replacement who subsequently fractured their femur presented a more difficult challenge. These fractures are not ammenable to internal fixation due to the presence of metal appliances and methylmethacrylate within the proximal intramedullary cavity. Nylon straps were used with nylon plates to achieve the stability required to allow healing.[34] This study provided no observations of avascularity of the femoral cortex

when utilizing the nylon straps for fracture fixation. Partridge and Evans believed that failures associated with the use of cerclage fixation are due primarily to improper technique. If principles of fracture fixation are understood and followed, prompt clinical healing should result.[34]

The Florio CPC (Circumferential Partial Contact) band was introduced by Florio in 1979.[44] This stainless steel band is undulated, or pleated, so that contact with the cortical bone surface is intermittant (Fig 1,2). These bands are designed to minimize cortical contact and thus avoid osseous necrosis under the band (Fig 3). The band is applied with similar technique as the Parham-Martin Band utilizing the Parham-Martin band clamp to tighten the device into place. The initial product study was performed on 20 mongrel dogs. Fractures of the femur were created and later stabilized using Florio CPC bands. The effect of the band on the blood supply to the cortex was evaluated by histologic examination. The results showed longitudinal areas of osseous necrosis in the areas of band-bone contact, but excellent blood supply was maintained to the remaining cortex for healing of the fractures.[44]

MATERIALS AND METHODS

Six mature ponies (mares and geldings, averaging 150 kg body weight) were used for the study. The ponies were randomly divided into two groups of three following the program described below.

Each pony received vaccination for tetanus[a] prior to surgery. Ivermictin[b] was given as a dewormer. Prairie hay fed ad lib and a commercial grain mix fed twice a day was provided throughout the study period. The ponies were submitted to a lameness evaluation to determine soundness prior to the project onset. Bilateral radiographic examinations (anterior-posterior, lateral-medial) were performed on the candidates to insure that all radii were free of periosteal reaction or detectable bone pathology; these were repeated at four and eight weeks postoperatively. Clinical evaluation consisted of daily physical examinations (rectal body temperature, pulse and respiratory rates, general attitude and appetite). At two, four, six, and eight weeks postoperation, the ponies were examined at the walk and trot for clinical signs of lameness. Group I ponies were euthanized at four weeks postoperation; the remaining three (Group II) were euthanized at eight weeks postoperation.

All ponies were sedated with xylazinec (1.1 mg/kg of body weight) intravenously prior to induction of anesthesia. Anesthesia was induced using ketamine[d] (2.2 mg/kg of body weight). After induction, an endotracheal tube was inserted; anesthesia was maintained with halothane[e] vaporized into oxygen and delivered through a semiclosed circle system.

With the pony in left lateral recumbancy, the anterior medial aspect of the left radius was clipped and aseptically prepared for surgery. A medial approach to the radial diaphysis was performed. A 20 cm curvilinear incision was made through the skin on the medial aspect of the radius, from the ventral border of the caudal superficial pectoral muscle distally to the medial tuberosity of the radius. The apex of the curved incision was located caudomedially on the limb over the flexor carpi radialis muscle, taking care to avoid the chestnut distally. The incision was made carefully to avoid incising the cephalic vein. The skin was dissected toward the craniomedial aspect of the radius. The cephalic vein and cutaneous branches of the musculocutaneous nerve were reflected caudally with their superficial fascial attachments as the subcutaneous incision was made cranially to these structures. The periosteum of the radial diaphysis was incised along a similar plane as the subcutaneous tissues. The periosteum was elevated utilizing periosteal elevators around the entire circumference of the radial diaphysis. A 22-gauge cerclage wire (ASIF) was placed around the proximal diaphysis utilizing a Synthes wire tightener.[f] Approximately 2 cm distal to the cerclage wire, a Parham-Martin cerclage band was placed around the radial diaphysis utilizing Richard's Parham-Martin Band Clamps[g] to secure its position. Two cm distal to the Parham-Martin cerclage band, a CPC strap was placed around the diaphysis using the above mentioned tightening device. The periosteum was closed using a simple continuous pattern of 2-0 polygalactin 910.[h] The subcutaneous fascia was closed in a similar manner. The skin was opposed using a simple interrupted pattern of 2-0 nylon.[i] The right radial diaphysis was approached , the periosteum was elevated, and

closed in the same manner except no cerclage devices were applied. Postoperatively, the radii were bandaged with nonadherent wound dressings,[j] stretch gauze,[k] and elastic tape[l] until suture removal at two weeks. The right radial diaphyses were utilized as controls throughout the study.

Gross postmortem examinations were performed on both radii of each pony. Special consideration was given to each radial diaphyseal area to determine any changes in contour, coloration, or character of the bone. Reaction to the various cerclage devices was noted.

Microangiography was used to examine the arterial supply of the control and altered radii. 50,000 IU of heparin sodium[m] was given intravenously prior to anesthetic induction. Each pony was anesthetized using xylazine followed by sodium thiamylal[n] (6.6 mg/kg of body weight). The brachial artery and vein of both forelegs were approached via bilateral axial incisions. Cannulas were placed in each artery and vein around which ligatures were used to secure their position. T-61[p] was administered intravenously to euthanize each pony. Micropulverized barium[q] made up in a 30 percent (by weight) suspension in physiologic saline was utilized as the infusion medium. The barium suspension was infused into the artery at a constant pressure of 120 mmHg. 120 mmHg is the normal systolic blood pressure in the horse. The venous outflow was allowed to run unchecked. Arterial infusion was continued until the venous outflow yielded almost pure barium suspension stained slightly pink with blood. The arterial infusion was then replaced to a barium sulfate formalin (10% buffered) suspension (30% by weight) to begin the fixative process. This infusion was continued until the venous efflux had a strong odor of formalin. The radii were then dismembered from the

body and stored enbloc in a 10 percent buffered formalin solution. Twenty-four hours later the skin was removed from the radius to allow proper fixation of the specimens. The muscle and fascia was removed prior to decalcifying the radial diaphysis. The diaphyses were embedded in a 1:1 mixture of parafin and beeswax to obtain an embedded tissue soft enough to section in 1 mm slices without cracking the tissue. The block was warmed to 37°C in a water bath to further soften the tissue prior to sectioning. A botanical microtome[r] was utilized to section the tissues for microangiography in a longitudinal and circumferential fashion across the cerclage trial areas.

The 1 mm tissue slices for microangiography were placed on glass plates[s] for soft x-radiography. A Picker 5-50 KUP unit with a water-cooled AEG-50A table Xray unit was utilized to produce the microangiographs. Exposure time was approximately 25 kV and 7-10 mA for 6.5-8 minutes at a focal film distance of 25.4 cm. The developed micioangiographic plates were protected by a covering of 5 percent Formvar solution.[t]

RESULTS

A. Clinical Observations

Postoperatively, the ponies showed transient swelling related to subcutaneous edema in the surgical area for 3 - 5 days. The bandages were removed, the surgical site inspected, and the limb was rewrapped as previously described every fourth day postoperation. Skin sutures were removed on postoperative day 14. There were no postoperative complications associated with wound healing at the operative site.

Lameness exams were performed at 2, 4, 6, and 8 weeks postoperatively for Groups I and II. Lameness or gait abnormalities were not identified in the ponies under study during any of the lameness evaluations.

B. Radiographic Evaluations

Radiographic studies performed preoperatively failed to identify radiographic evidence of any preexisting pathology on the radii. Postoperatively, Pony 1 in Group I showed a minimal amount of periosteal reaction on the medial aspect of the radial diaphysis between the cerclage devices. Postoperative radiographic examinations of the other ponies in both groups were within normal limits (Fig 4,5).

C. Gross Postmortem Observations

Gross postmortem examination of the operative areas of the Group I radii showed normal soft tissue healing for one month postoperation. Resolving hematomas were observed in areas where the periosteum had been

elevated. Dense pale fibrous tissue surrounded the larger cerclage devices (Parham-Martin band and CPC band) in Group I. No changes in gross appearance of bone color or contour was identified.

Gross examination of the soft tissue healing of Group II radii was considered normal with no abnormalities noted. The control radial diaphyses of Group II showed thick, pale periosteum on the medial aspect where it had been surgically incised. The periosteum over the cerclage appliances in Group II radii was thickened and appeared more fibrotic on the medial aspect of the radius than Group I. Additionally, the color and contour of all Group II radial diaphyses appeared normal.

The cerclage wires, Parham-Martin bands and CPC bands were intact on postmortem examination. All of the appliances tightly encircled the radial diaphyses. None of the appliances had shifted or moved from their original position.

D. Microangiographic Evaluation

All specimens were adequately perfused with the barium suspension to allow microangiographic evaluation. The technique of whole limb perfusion appeared to be adequate for this type of study.

The control radii of Group I and Group II exhibited the same vascular patterns to the radial diaphysis. Longitudinal sections of the microangiographic preparations typically demonstrated medullary arteries ascending and descending in the medullary cavity (Fig 6). These vessels divide to enter the endosteal cortex at numerous sites along the diaphysis. Very few periosteal vessels can be identified entering the outer cortex. Crossectional preparations of the radii demonstrates the endosteal arterial supply to the entire cortical thickness on the

medial, anterior, and lateral aspect of the diaphysis (Fig 7). On the posterior radial aspect, which has dense fascial attachments in the pony, a few small periosteal vessels could be noted supplying the outer portion of the cortex. Along the anterior aspect, a periosteal vessel could be seen coursing along the cortex, but not entering it.

The specimens derived from the diaphyses encircled with cerclage devices were also well perfused. No microangiographic differences could be noted between Groups I and II and therefore will be discussed as a single group. Crossectional microangiography of the radii beneath the cerclage wire demonstrated the presence of multiple medullary arterioles (Fig 8). Smaller vascular branches could be seen entering the endosteal surface and radiating peripherally through the cortex. The vascular supply beneath the cerclage wires of all operated ponies were similar. Crossectional microangiography of the radii under the Parham - Martin band shows the same medullary arteries as previously discussed (Fig 9). Many small vessels are shown entering the endosteal cortex in a radiating manner, similar to that in the case of the cerclage wire. Longitudinal microangiography demonstrated the vascular patterns under the Parham - Martin band to be no different from the control (Fig 10). Microangiography from beneath the CPC band failed to reveal any impairment of vascular supply at the points of longitudinal contact (Fig 11). Beneath the ridges of the CPC band, normal endosteal to periosteal vascular supply exists. A longitudinal microangiogram (Fig 10) demonstrates the medullary arteries and penetrating endosteal vessels beneath the CPC band.

The control radii and altered radii of Groups I and II demonstrated vascular patterns that were consistent and behaved the same in both the control and altered radii.

DISCUSSION

The surgical procedure itself did not produce adverse effects in the ponies under study. All incisions healed by first intention with standard preoperative, operative and postoperative care. This suggests that the metallic implants were compatable with normal healing of the surgical wound. When following the appropriate recommended technique of application, the cerclage devices were relatively simple to apply, and remained in place on unfractured bone without mechanical failure throughout the duration of the study. The cerclage wires and Parham - Martin bands conformed to the bone well. The CPC band was more difficult to place around the long bone, especially in heavily muscled areas. This difficulty was associated with the need for additional retraction to provide space to pass the pleated CPC band around the bone. This excessive dissection and retraction was not needed for the round cerclage wire or flat Parham-Martin band. The CPC tightened snugly into place, however it did not conform as well as the other appliances on the posterior aspect of the radius.

The absence of lameness following the application of cerclage appliances suggests that these devices, when properly applied to the equine radius, do not adversely affect ambulation.

All radiographic studies except one (Pony 1, Group II) were within normal limits. This pony developed radiographic evidence of a slight periosteal proliferation on the medial aspect of the radius. This could perhaps be explained by the surgeons inability to completely close the periosteum after the the cerclage appliances were placed. The dead

space remaining may have filled with an organized blood clot which subsequently calicified. The remaining radii did not exhibit radiographic changes. The cerclage devices, when properly applied, should be placed firmly around the bone, cause no radiographic signs of osseous change, and remain stable at the location where originally placed. If the devices were loosely applied and had the ability to move or if the blood supply to the cortex was sufficiently damaged, periosteal reaction would be identified via radiography. Evidence of osseous reaction was not observed thereby confirming that the cerclage devices had neither loosened and migrated nor damaged the cortical blood supply.

Gross postmortem examination of the radii in Group I and II were normal for the stage of healing occurring at the time of euthanasia. All cerclage devices were noted to be firmly in position with no discoloration in adjacent tissues. This indicated that the cerclage devices were inert and nonreactive during the two month study.

Minor proplems were encountered when performing the barium perfusions. Despite the large size of the ponies relative to the dog which is most commonly studied via microangiography, only a few changes in perfusion technique were needed to perfuse the pony radii. The gravity pressure system described in previous studies was not suitable for perfusion of the entire pony limb. The present study utilized a pressure system derived from hand pumped fluid delivery pressure bags. This permitted a more effective method of administration for the barium infusion with appropriate perfusion of bone.

Human and canine afferent cortical blood supplies follow similar flow patterns through the cortex. Bone perfused in a normal canine long

bone shows vastly increased perfusion when the dog becomes nonweightbearing on the opposite limb.[29] Evaluation of the equine unaltered right radial microangiograms were compared with microangiograms from the dog.[29] Because none of the ponies exhibited lameness during the study, comparisons between equine and canine bones were assumably made in the resting, or normal, state. It appears that the equine long bone has a greater number of medullary arteries that the canine. These appear to be multiple and branching, which is significantly different from canine and human long bones where the numbers of ascending and descending medullary arteries are few.[29]

This study supports the previously described theory of centrifugal supply of blood through the cortex. Brookes (1971) states that the major factor maintaining centrifugal blood flow through the cortex is the intravascular pressure gradient from endosteum to periosteum.[2] Existance of this pressure gradient has been observed by surgeons who, when stripping periosteum off long bone, note punctate venous bleeding occurring on the cortical surface.[29] Punctate cortical bleeding was observed in each of the surgeries performed on the ponies in this study.

The occurrence of centrifugal blood flow in equine cortices is further confirmed by microangiographic methods. Small arteries can be seen entering the endosteal cortex after branching from a large medullary artery (Figs 6,7).

This study also shows similar periosteal blood supply as in Rhinelander's work.[2,6,7,9,29] Rhinelander stated the periosteal vessels supply the outer one third of the cortex in areas of dense fascial attachments. In Fig 7, small periosteal vessels can be noted entering the posterior aspect of the radius in the area of deep digital flexor

and flexor carpi ulnaris muscle origins. On the anterior aspect of the radius (Fig 7), a periosteal vessel can be shown coursing around the circumference of the bone, yet no smaller branches can be found entering the cortex. In normal healthy equine long bone, the blood flow appears to be centrifugal; periosteal afferent contribution to the cortex is minimal.

Rhinelander, using microangiographic and histologic techniques, demonstrated that properly applied cerclage wires do not obstruct cortical blood supply. Cerclage wires are round and engage minimal contact area on the bony cortex thus maintaining adequate centrifugal blood supply.[3,10.29] Equine cortical blood flow beneath the cerclage wire was not interrupted. The minor periosteal supply to the outer one-third of the cortex in areas of dense fascial attachments does not appear to be dissrupted in this study; a finding which agrees with previous microangiographic studies of cerclage wires.[29]

The Parham-Martin band, because of its width, occludes canine cortical blood flow, causing local ischemia by blocking the efferent flow of blood.[7,29] The cortical blood supply beneath the Parham -Martin band on the equine cortex did not show a loss of vascularity. Beneath the Parham-Martin bands on both longitudinal and crossectional microangiograms, the small medullary arteries are observed entering the endosteal surface and radiating in the same manner as under the cerclage wires. This is a significant difference from previously described canine and human cortical afferent blood flow patterns.[29] Equine cortical bone may have a greater "radial" or longitudinal blood flow than the canine long bone. If an equine endosteal artery entered an area beneath a 10 mm. Parham-Martin band, it would require 5 mm. of

longitudinal (proximal and distal) blood flow to provide proper afferent and efferent vascularization beneath the cerclage device. A second possible explanation may be that venous outflow could drain into the medullary cavity beneath the Parham-Martin band. However, this concept disagrees with the vast amount of previous research evidence that supports the centrifugal flow of blood.

The afferent blood flow beneath the CPC band appeared to have been uninterrupted by the cerclage appliance. Therefore, the intermittant longitudinal areas of cortical contact did not impair the centrifugal blood flow.

The results of this equine cortical blood flow study indicate that all three types of cerclage devices could possibly be utilized in the stabilization of an equine long bone fracture. However, early callus formation depends upon the periosteal blood supply. These periosteal arteries approach the callus site perpendicular to the long bone axis.[29] The Parham-Martin band is too wide for adequate callus formation in the dog. It is possible that it may impair healing in the equine also. The CPC band, with its pleated, fenestrated design, may allow sufficient periosteal blood supply for callus formation.

Further studies utilizing the Parham-Martin and CPC bands in clinical or research fracture conditions are needed.

SUMMARY AND CONCLUSION

Three different cerclage devices were surgically implanted around the diaphysis of the radius of 6 ponies and clinical, radiographic, gross postmortem and microangiographic observations were performed over a two month period.

No clinical signs of lameness were observed in any of the ponies during this study. No significant osseous reaction could be identified on the radiographic evaluations. Gross postmortem observations included a thickened fibrotic appearing periosteum on the medial aspect of the radial diaphysis with no changes in the contour or coloration of the bone.

Microangiographic studies of the equine right radius demonstrated a greater number of medullary arteries than the dog. The radii appeared to be in a resting state with centrifugal blood flow. Microangiographic studies of the afferent vascular supply beneath all three cerclage devices appeared normal. The normal blood flow identified beneath the Parham-Martin band on the equine radius was significantly different from previous canine or human studies.

Conclusions drawn from this study include:

1.) Cerclage wires, Parham-Martin bands, and Circumferential Partial Contact bands were nonreactive in equine tissues and were not difficult to apply.

2.) Normal afferent vascular supply to the equine long bone cortex was centrifugal. This finding paralleled the observation of centrifugal cortical blood flow as described in canine and human long bones.

3.) Afferent cortical blood flow appeared to be more longitudinal, or flow more proximal and distal from entry into endosteum and exit from periosteum in the horse. The normal cortical blood supply observed beneath the Parham-Martin band in the horse was significantly different from previous canine studies and formed the basis for suggesting a greater longitudinal blood flow.

4.) Microangiographic findings suggest that cerclage wire, the Parham-Martin band, and the CPC band do not adversely affect the centrifugal cortical blood flow to the intact radial diaphysis.

FOOTNOTES

a. Encevac - T, Cutter Laboratories, Inc., Shawnee, Kansas 66201

b. Equalan, Merck and Co., Inc., Rahway, New Jersey 07065

c. Rompun, Cutter Laboratories, Inc., Shawnee, Kansas 66201

d. Ketaset, Bristol Laboratories, Syracuse, New York 13201

e. Halothane, Halocarbon Laboratories, Inc., Hackensack, New Jersey 07601

f. Synthes LTD., Wayne, Pennsylvania 19087

g. Richards Medical Co., Inc., Memphis, Tennessee 38116

h. Vicryl, Ethicon, Inc., Sommerville, New Jersey 08876

i. Ethilon, Ethicon, Inc., Sommerville, New Jersey 08876

j. Telfa, Kendall Co., Baston, Massachusetts 02101

k. Sta-tite, Cheesebrough - Pond's Inc, Greenwich, Connecticut 06830

l. Elasticon, Johnson and Johnson, New Brunswick, New Jersey 08903

m. Haparin, Elkins-Sinn, Inc., Cherry Hill, New Jersey 08034

n. Biotal, Bio-Ceutic Laboratories, Inc., St. Joseph, Missouri 64502

p. T-61, American Hoechst Corp., Somerville, New Jersey 08876

q. Novopaque, Picker International, Highland Heights, Ohio 44143

r. AO Spencer Model 900 table microtome, VWR Scientific Co., P.O. Box 3200, San Fransisco, California 94119

s. Kodak type 649-0, Eastman-Kodak Co., Rochester, New York

t. Formvar, Monsanto Chemical Co., St. Louis, Missouri 08903

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FIGURE 1
The Circumferential Partial Contact band prior to surgical implantation.

FIGURE 2
The Circumferential Partial Contact band, side view. The longitudinally pleated design provides intermittant areas of cortical contact.

FIGURE 3
The schematic crossectional view of the Circumferential Partial Contact band demonstrates the intermittent areas of cortical contact which allow centrifugal bloodflow to occur.

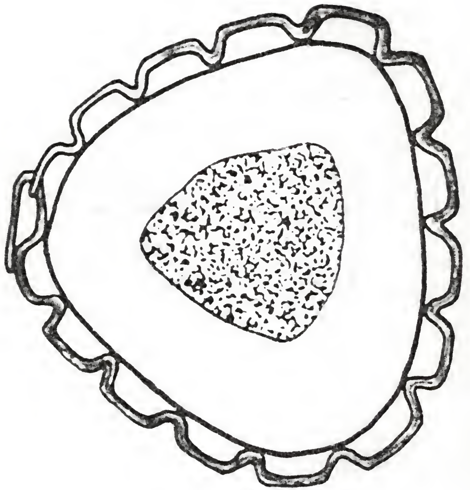

FIGURE 4
The anterior - posterior radiograph of the radius of Pony 1, Group I demonstrates the position of the cerclage devices.

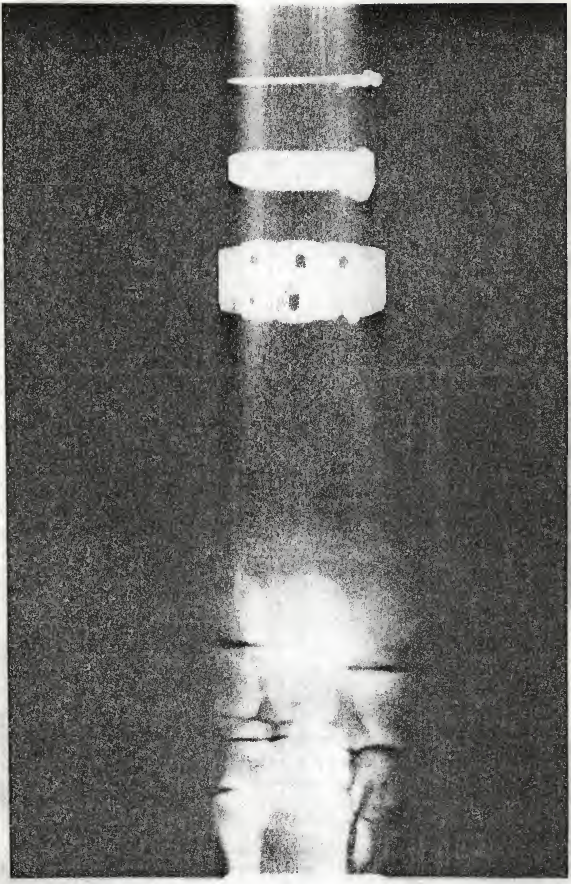

FIGURE 5
The lateral - medial radiograph of the radial diaphysis of Pony 1, Group I demonstrates the position of the cerclage devices.

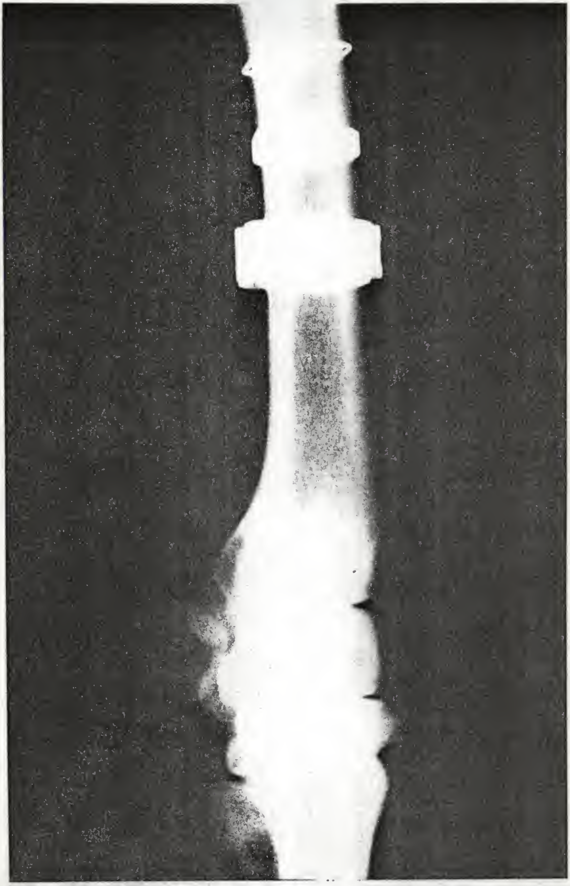

FIGURE 6
This longitudinal section microangiograph is of the control radius of Pony 5, Group II. Medullary arteries can be identified ascending and descending in the medullary cavity.

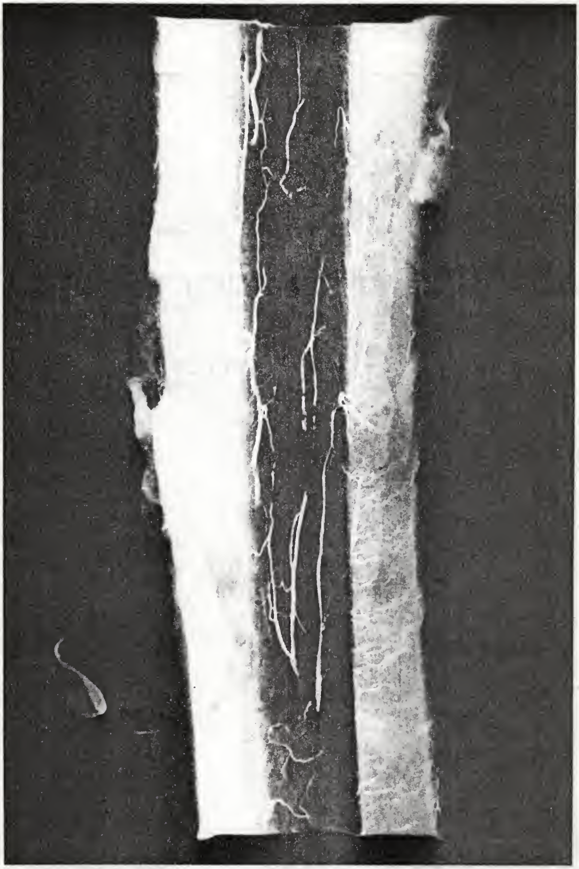

FIGURE 7

This crossectional microangiograph is of the control radius of Pony 3, Group I. Multiple medullary arteries are demonstrated. Vessels entering the endosteal surface radiate to supply the cortex. A few small periosteal vessels can be identified entering the posterior radial cortex, seen at the right of this photograph.

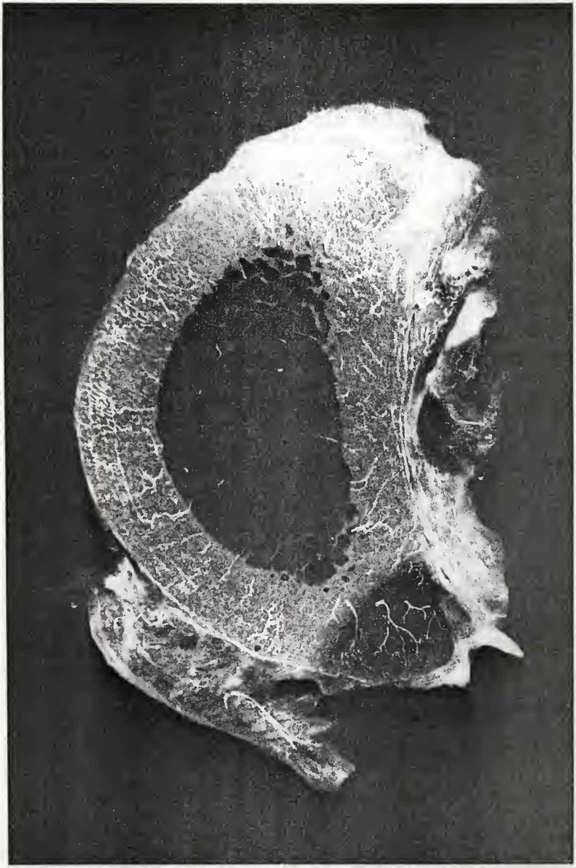

FIGURE 8
This crossectional microangiograph is through the cerclage wire of Pony 1, Group I. Small vascular branches can be seen entering the endosteal surface and radiating peripherally through the cortex.

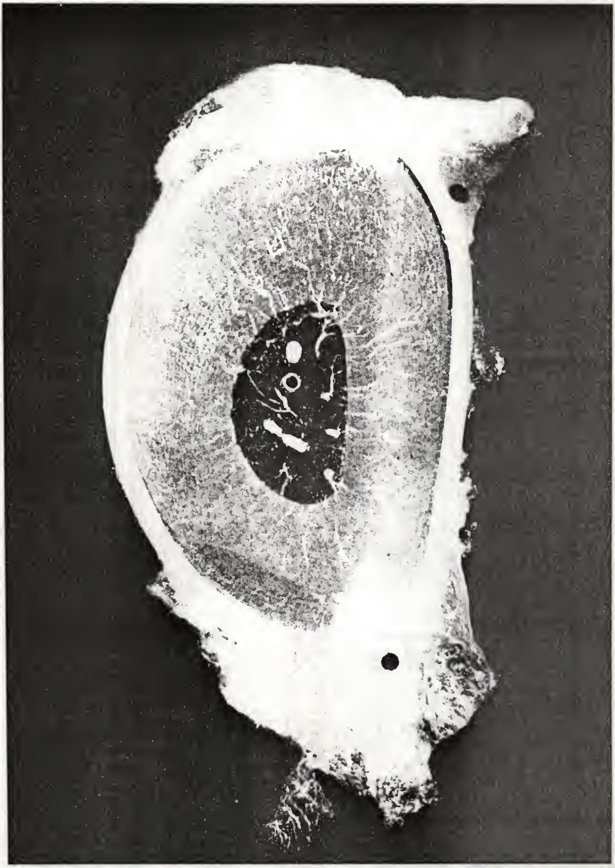

FIGURE 9

This crossectional microangiograph is through the Parham-Martin band of Pony 1, Group I. The vascular pattern is similar to the control radii and the cortical areas beneath the cerclage wires.

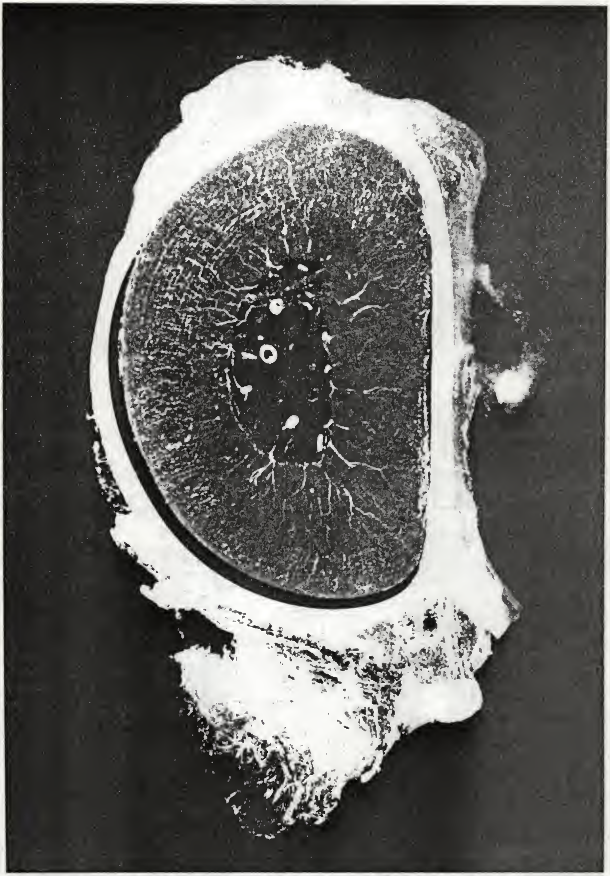

FIGURE 10
This is a longitudinal section microangiograph with the three cerclage devices in place in Pony 2, Group I. No impairment of vascular supply can be identified beneath the cerclage devices.

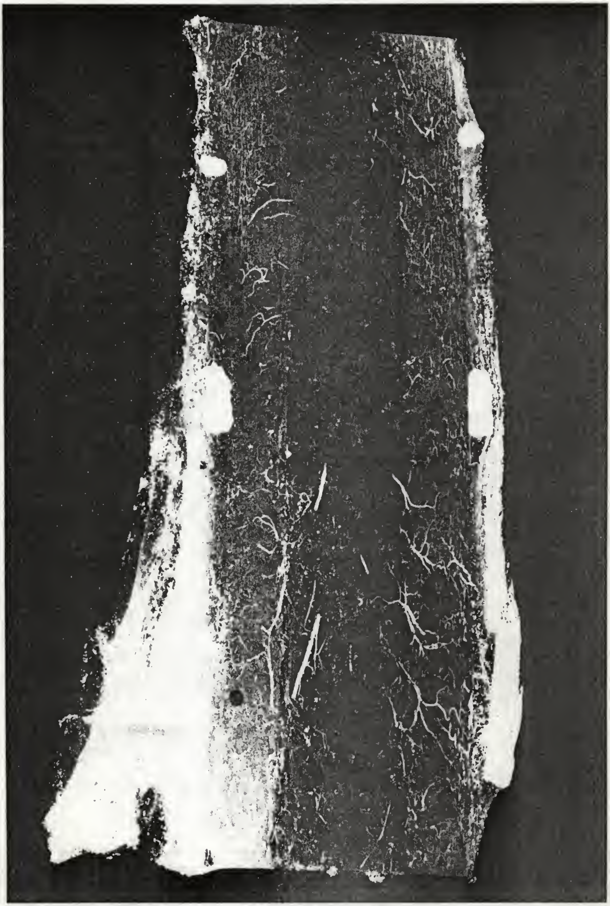

FIGURE 11
This is a crossectional microangiograph beneath the CPC band of Pony 6, Group II. The vascular supply appears unimpaired by the cerclage appliance.

NORMAL BLOOD SUPPLY TO EQUINE RADII
AND ITS RESPONSE TO VARIOUS CERCLAGE DEVICES

by

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AN ABSTRACT OF A MASTER'S THESIS

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1984

ABSTRACT

The purpose of this investigation was to study the normal arterial blood supply to the adult pony radial diaphysis and to characterize the reaction of the radius and its blood supply when three different cerclage devices were applied.

Three cerclage devices (a cerclage wire, a Parham-Martin band, and a Circumferential Partial Contact band) were applied 2 cm. apart on the left radial diaphysis of 6 adult ponies. The right radial diaphysis performed as the control throughout the study. Three ponies were euthanized after 4 weeks; the remaining 3 were euthanized after 8 weeks. The ponies were evaluated for lameness, and by radiographic, gross postmortem and microangiographic observations.

No clinical signs of lameness occurred in the ponies during the study. No significant soft tissue or osseous reaction was identified on radiographic or gross postmortem evaluations.

Microangiographic studies of the equine right radius (control) demonstrated the presence of a centrifugal blood flow pattern. Greater numbers of medullary arteries exist in the equine as compared to canine and human long bones. No changes in centrifugal blood supply were identified beneath the cerclage devices. The blood flow beneath the Parham-Martin band on the equine radius was unaffected by the band; a finding that was significantly different from previous canine or human studies in which the osseous vascular supply was occluded causing ischemic necrosis beneath the cerclage device.